Radiology Corner

Traumatic Brain Injury: Imaging Spectrum from Mild to Severe Closed Head Injury

Guarantor: 2LT Sean Meagher, MSC, USAF[1]
Contributors: 2LT Sean Meagher, MSC, USAF[1]; LT Alexander Galifianakis, MC, FS, USN[2]; LCDR David Jannotta, MC, USN[2]; Pavel Krapiva, MD, PhD[2]; COL Les Folio, MC, USAF[1, 2]

Note: This is the full text version of the ***Radiology Corner*** *question published in the October 2008 issue, with the abbreviated answer in the November 2008 issue.*

The authors present a case of a Diffuse Axonal Injury (DAI) that is evident on MRI, though not on CT. In this full-text version we present two more cases of parenchymal injury in increasing severity. There is a continual clinical and imaging spectrum of severity of head trauma: from seemingly trivial falls or car accidents to blast exposure at various distances, to high velocity penetrating and perforating ballistics. Mild Traumatic Brain Injury (mTBI), has received significant publicity in current military operations. Our case illustrates one of the more subtle findings on imaging, followed by more severe cases with more extensive findings. We present companion closed head injury cases of increasing severity of parenchymal damage to pictorially outline the imaging spectrum, then introduce penetrating trauma and a standard report with hopes to further set the future imaging perspective.

Introduction

The following cases should illustrate the role of imaging in closed head injury where TBI is suspected. Mild TBI is defined as injury with loss of consciousness or altered mental status (e.g., dazed or confused),[1] and the term concussion is sometimes used synonymously for mTBI.[2] Not all significant brain injury may be seen on CT or MRI,[3] so optimal imaging is up to the clinician in concert with the radiologist. Therefore, positive MRI and, in one case, CT with the most subtle findings are presented here with representative cases.

Patient 1: A 36 year-old man presents for evaluation after exposure to an explosive blast during combat operations. Injury history, mental status, and neurological exam results were not available for review.

Summary of Findings:

The CT scan obtained in the immediate post-traumatic setting was unremarkable (Fig. 1A). Further investigation with MRI, however, revealed imaging evidence of traumatic brain injury (Fig. 1B). In this case, the T1 and T2 weighted images were unrevealing. The abnormality is demonstrated on the gradient echo (GRE) images where punctate foci of low signal are noted in the white matter of the right frontal lobe and in the superior aspect of the right parietal lobe. These findings most likely represent areas of parenchymal hemosiderin deposition due to traumatic shearing injury.

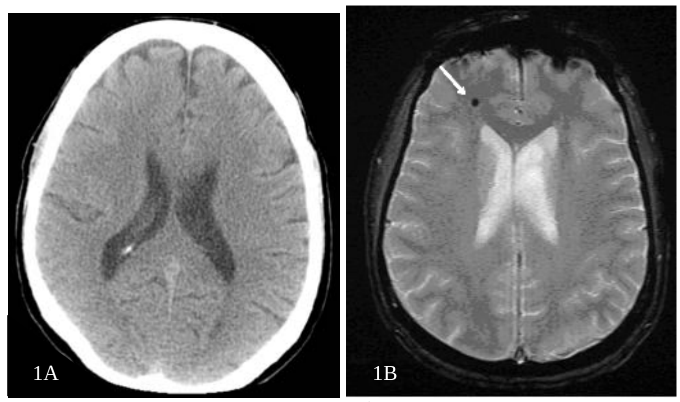

Fig. 1 Non-Enhancing CT (NECT, A) fails to demonstrate an abnormality. MR Gradient Echo Image at the corresponding anatomic region (B) demonstrates a focus of low signal in the anterior radiations of the right frontal lobe (arrow). This focus represents hemosiderin deposition consistent with shearing injury or diffuse axonal injury.

Diagnosis:

Diffuse Axonal Injury seen only on Gradient Echo MRI sequence (not seen on other MRI sequences or CT).

Patient 2: The patient is a 40-year-old man status post blast injury. See CT and MRI below:

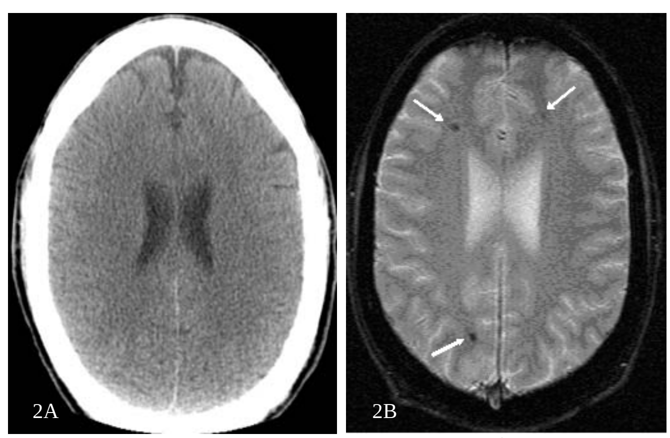

Fig. 2 Non-contrast CT (A) on our second case fails to demonstrate abnormality. Axial GRE (gradient echo, B) image at the corresponding region shows multiple low signal foci, two in the right hemisphere and a less conspicuous focus in the left frontal lobe consistent with hemosiderin deposition (arrows).

[1] Department of Radiology and Radiological Sciences; Uniformed Services University of the Health Sciences, Bethesda, Maryland 20814-4799
[2] Walter Reed Army Medical Center, Washington, DC 20307
Reprint & Copyright © by Association of Military Surgeons of U.S., 2006.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **NOV 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**
4. TITLE AND SUBTITLE **Traumatic Brain Injury: Imaging Spectrum from Mild to Severe Closed Head Injury**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Uniformed Services University of the Health Sciences,Department of Radiology and Radiological Sciences,4301 Jones Bridge Road,Bethesda,MD,20814**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Summary of Findings:

The initial CT was normal (Fig. 2A). On MRI, however, punctate foci of decreased signal intensity were evident in both hemispheres on gradient echo sequences consistent with hemosiderin deposition, some at the interface between gray and white matter. Other MRI sequences were negative.

Diagnosis:

Diffuse Axonal Injury seen on MRI and not on CT

Patient 3: The last patient is a 27-year-old male pilot who suffered traumatic brain injury in a helicopter mishap.

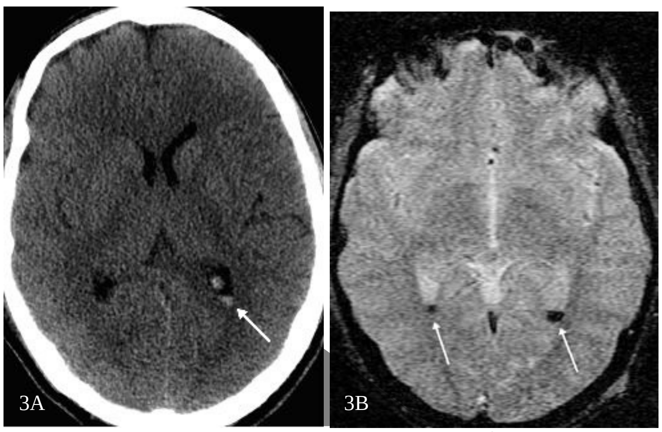

Fig. 3 NECT (A) demonstrates hyperdense layering of blood product in the posterior horn of the left lateral ventricle (arrow). Axial GRE (B) at the same level showing layering blood in both posterior horns (arrows), left more than right. Note how the right blood-fluid level is more conspicuous on the MR.

Summary of Findings:

Non contrast CT demonstrates intraventricular hemorrhage (Fig. 3A) with area of low attenuation in the corpus callosum (Fig. 4A), as well as a dense focus in the right frontal lobe (Fig. 5C). On MRI these areas of involvement are shown to be more conspicuous (Fig. 4 and 5). The GRE images reveal multiple small foci of hemorrhage within the corpus callosum adjacent to the corona radiata, in the splenium, and in the left genu (Fig. 4D). Additional foci were noted in the left thalamus and at the vertex (not shown).

These areas of involvement are seen on T2-weighted images and are even more apparent on the FLAIR images (Fig. 4B, 5B). The T1 and FLAIR images also demonstrate further involvement of the right parasagittal-frontoparietal junction (Fig. 5A, B). This focus of T1 bright signal is consistent with methemoglobin, which corresponds with the area of contusion on CT (Fig. 5C). The constellation of these findings are consistent with diffuse axonal injury, some with hemorrhagic foci.

Diagnosis:

Intraventricular hemorrhage, with a more extensive involvement of Diffuse Axonal Injury revealed on MRI (when compared to NECT).

Discussion

The authors have shown a sample of various findings of parenchymal injury found in closed head trauma. The spectrum of findings from the most mild to the most severe begins with negative CT and negative MRI findings in mTBI. Less mild head injuries (some mild, some moderate) will be detected on imaging earlier on particular sequences of MRI before others, and certainly before CT. As one progresses up the scale of severity, several sequences become positive on MRI; finally, severe head injuries eventually become positive on both MRI and CT. Table 1 outlines this range of mild, moderate, and severe head injury from a clinical perspective.

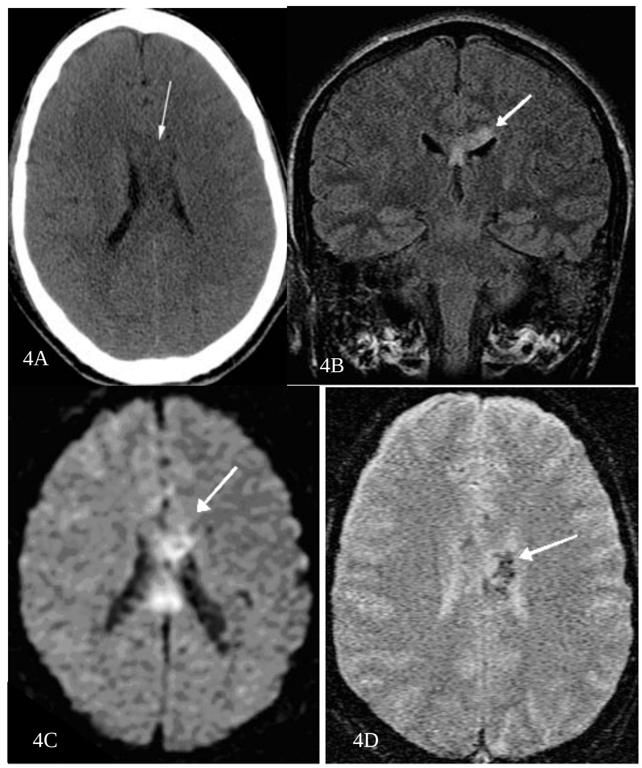

Fig. 4 NECT (A) shows low density area in the callosal parenchyma consistent with edema (arrow). Coronal FLAIR sequence (B) showing fluid signal within the corpus callosum (arrow). DWI sequence (C) shows restricted diffusion at the same level (arrow). GRE sequence (D) showing associated blood products at same area (arrow).

The authors believe that evolving imaging advances may redefine imaging findings in mTBI in the near future. We have shown how GRE and DWI can increase sensitivity of detection on MR. Application of DTI, 3T MRI, and temporal lobe volume imaging may help increase sensitivity and is worthy of further investigation. A recent study with 3T MRI is promising in detecting mTBI.[4] For example, trauma has been shown to result in white matter loss and hippocampal atrophy. There may be useful imaging corollaries between neurodegenerative changes and mTBI. In addition, trauma changes morphometric temporal lobe relationships and is associated with poorer memory performance.[5] On the other end of the cognitive spectrum, one study demonstrated that taxi drivers in London had greater gray matter volume than controls (bus drivers) in mid-posterior hippocampi and less volume in anterior hippocampi due to more demand on navigational spatial orientation.[6,7] London taxi drivers have stringent requirements and periodic testing of location knowledge, routes and even hospital locations and capabilities. This indicates that there is a capacity for local plastic change in the healthy adult brain in response to environmental demands. We speculate that this sensitivity of volumetric MRI could therefore be promising in detecting early changes in mTBI.

More importantly for now, we show a parallel imaging spectrum of severity as a guide for providers to tailor imaging with clinical suspicion. Lastly, a standard brain MRI at many institutions may not include GRE (detecting early hemorrhagic foci) or DWI (early detection of non-hemorrhagic processes) routinely, so specifically mentioning mild to moderate head injury and other important traumatic history (such as blast, roll-over MVA, etc.) will help radiologists help providers detect abnormalities earlier and at a less severe level.

We are currently seeing deployed military personnel routinely working in hostile environments with significant and dangerous exposure to potentially injurious blasts. Over time, a "signature mechanism of injury" has emerged due to inconspicuous weapons used in current operations. Blast injuries demonstrate a staggering, unique, and troublesome medical problem for physicians in theater, with an average of 30 patients needing medical care for blast injury-caused injuries per day among U.S. military personnel in 2005.[8] The majority of TBI seen is mild TBI (about 84%), with the rest evenly divided among moderate, severe, and penetrating TBI.

Xydakis notes that conventional weapons (that is, not chemical, biological, radiological, or nuclear [CBRN]) injure in patterns based on three mechanisms, or the "3 B's of injury": ballistics, blasts, and burns.[9] We have recognized that blasts must be further divided into blast displacement and blast overpressure (giving us "4 B's of injury").

The physical mechanics of an explosion typically are modeled by the following pattern: primary blast injury comes from a wave of blast overpressure compressing the body and hollow air-filled organs; secondary injury results from flying debris and projectiles that have ballistic properties; tertiary injury happens when the patient's body becomes the flying object and collides with other objects (walls, vehicles, etc). Quaternary (sometimes referred to as miscellaneous) injury comes from burns from the blast heat or inhalation of gases and smoke released in the explosion.[10]

Regular use of body armor, reinforced vehicles, and other protective equipment has resulted in a higher survival rate in injured soldiers that would have died of wounds in previous wars from ballistic injuries.[11] Although these precautions are providing significant life-saving protection against flying fragments and blast displacement, a wide range of subtle injuries are hurting troops that may potentially go unnoticed and untreated by health care providers. These subtleties are a major concern, especially mTBI that is serious enough to cause neurocognitive changes, but yet subtle enough to avoid detection on traditional CT imaging in theater.

Ordering a CT on all potential head injuries to look for possible signs of injury may not be the best use of theater resources and may drastically disrupt the flow of casualty traffic through the trauma center. Additionally, two of the cases above describe injuries that were not evident on CT, but showed abnormalities on MRI. However, MRI is not used in theater for many reasons. First, environmental conditions would place incredible stress on the scanners, and necessary maintenance would not be consistently available. Additionally, casualties with metallic gear, unexploded ordinance, and potential embedded fragments with metal parts cannot be scanned due to the magnetic field and possible damage to the patient and scanner. Lastly, field conditions make it difficult to maintain a magnet free zone with non-ferromagnetic medical equipment.

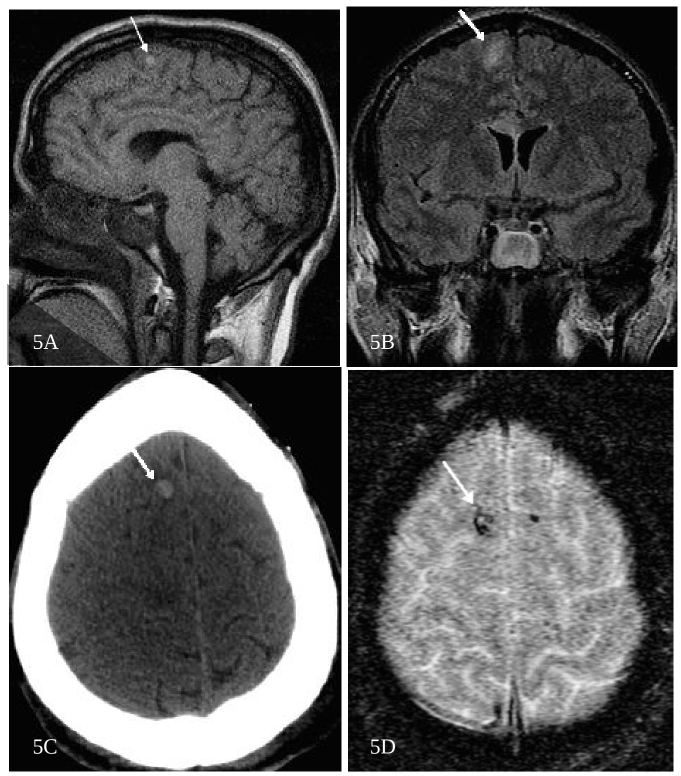

Fig. 5 Sagittal T1-weighted image (A) showing a small focus in right frontal lobe at the gray-white junction, consistent with methemoglobin (arrow). Coronal FLAIR (B) at the corresponding site shows focal high signal (arrow) consistent with a small area of edema. NECT (C) shows small round hemorrhagic focus in the right frontal lobe (arrow). GRE sequence (D) showing associated blood product (arrow) in same region.

In the fog of war and heat of battle, respecting the ferromagnetic free zone would be improbable and compromise would be inevitable. Rapid triage and treatment requires expeditious movement of patients for urgent studies and would likely result in inadvertent entry into the scanning area without proper screening, thus resulting in harm from flying metallic objects. With these constraints in mind, other methods of screening for neurological injury in combat must be cultivated. It is of the authors opinion that there is no role (currently) for MRI in deployed combat hospitals.

Sometimes, there are no outward signs of exposure to blasts and the affected individual may not accurately recall how close they were to an explosion. When considering whether or not an individual has any mTBI, one must note any alteration or loss of consciousness as well as post-traumatic amnesia.[12] A study by Ryan et al in 2003 identified physical and cognitive symptoms that were self-reported a few days or weeks after injury in high rates among concussion patients; these include headaches, dizziness, fatigue, noise and light sensitivity, memory deficits, attention and concentration deficits, and executive function deficits. Notably, headache and dizziness were reported immediately after injury as well as later in time.[13]

Cognitive changes are typically screened before treatment with tools such as the Military Acute Concussion Evaluation (MACE), Repeatable Battery for the Assessment of Neuropsychological Status (RBANS), Cognitive Stability Index (CSI), and Automated Neuropsychological Assessment Metrics (ANAM4). These are all used along with the patient's history, medical symptoms, and physical exam to confirm TBI and determine treatment options.[2]

Another reliable sign of blast exposure that physicians must look for is tympanic membrane rupture from blast overpressure. This injury can occur at relatively low pressures: rupture or perforation can be caused by a pressure as low as 2.5 kg/cm^2, or 245.2 kPa.[8] This value may be low for an explosive blast, but when examined in a relative decibel level, this is an incredibly loud exposure, approximately equivalent to 202 dB[14]; a literature search showed that rifle and small arms fire can have decibel levels ranging from 148.5 dB (0.5321 kPa) to 160.9 dB (2.218 kPa).[15] Since decibel measurements follow a logarithmic scale, this means that rupture-inducing blasts have roughly 111 to 461 times the air pressure impact of close range rifle or small arms gunfire. The ear is most vulnerable to this type of damage; the structures that normally amplify sounds also amplify damaging pressure waves. Because of this sensitivity, rupture may be the only sign of blast exposure. It is vital that tympanic membranes be checked during the physical exam when caring for patients from an explosion as this may indicate the need for further treatment.

Another study by Xydakis et al observed that tympanic membrane pathology was frequently overlooked during treatment due to its understated nature.[8] Blast ear injury ranges from sensorineural acoustic trauma to disruption of middle and inner ear structures. They investigated associations between perforation and loss of consciousness among male U.S. soldiers exposed to blasts in combat zones and found that the overall incidence of perforation was 35.2%, with 37.8% being bilateral; the incidence of loss of consciousness was 35.7%, and there was a significant association between the two events (relative risk, 2.76; 95% confidence interval, 1.91 to 3.97).

The study also found that of 45 of 74 patients (60.8%) with tympanic membrane perforations demonstrated a loss of consciousness, a possible sign of mTBI. Hearing protection reduced the risk of rupture, but did not change the association observed (11 of 17 rupture patients with loss of consciousness, 64.7%), leading them to conclude that physicians should suspect neurological injury when treating blast survivors with tympanic membrane ruptures.

It is important to note that blasts are not the only potential cause of mTBI in the active deployed population. Activities that put personnel at risk for concussions must be assessed for potential harm, ranging from those that are more obvious such as motor vehicle accidents to the subtle, like slipping and falling from one's own height.[16,17]

"No head injury is too trivial to ignore"
(Hippocrates, 460-377 BC, in Ingebrigsten)[18]

There are many recent advances in TBI treatment. Decompressive Craniotomy has been a mainstay of severe penetrating head injury in current conflicts. It allows immediate room for swelling while improving intracerebral bloodflow. An interesting surgical craniotomy technique was developed at the onset of the recent campaign in Iraq for more severe injuries to immediately relieve intracranial swelling following a blast while preserving the portion of skull removed.[19] This involves taking the removed skull flap, implanting it into the abdomen temporarily to allow for adequate blood flow and easy access for recovery and replacement later. This keeps the patient's own bone viable. Stereolithography is now used to digitally reconstruct the patient's skull and custom design materials that can be used in cranial reconstruction.[20]

Penetrating head injury

Although our primary focus of this work was a closed head injury spectrum, an introduction to more severe open penetrating and perforating head injury (such as dural compromise from skull or facial bone fracture) is worthy of mention. This should help put the presented spectrum in perspective for future research on extensions of grading and predictability. Survivability surrogates or CT grading of penetrating trauma may be able to be determined after review of consistent data collected from recent deployed experience through accurate, detailed data recording. Although a succinct score such as a "CT GCS" is not likely anytime soon, this is not an impossible future concept to consider based on clinical record review, more standard and objective CT reports (discussed in further detail and organized below), and mechanism of injury.

Increasing demand for imaging in trauma with the advent of MD CT (MultiDetector CT) has also seen an increase in the need of preliminary reports. Although voice recognition is helping with this somewhat, there is still a paucity of interoperability of RIS-HIS (Radiology and Hospital Information Systems) between PACS (Picture Archiving and Communications) and the EHR (Electronic Health Record). This has kept the necessity of preliminary reports, which are often handwritten. Checklist or checkbox report formats have relieved that somewhat, with some preliminary research demonstrating provider satisfaction.[21] Additionally, deployed radiologists often use a standard format for reporting penetrating head injury for immediate diagnosis and treatment.

This saves time by avoiding a repeat inspection of anatomic regions or areas and allows referring providers to visually scan the reports in a quick and efficient manner by knowing where to look for specific data. Standard reporting also allows for more reproducible data records for long term epidemiologic analysis.

An example is shown below of a simple checklist for head CT that was created to include missile path, involvement, and other findings important for individual and epidemiologic considerations. The radiologist simply circles appropriate findings and adds any comments (Table 2). This allows neurosurgeons, ER physicians and other providers to get a quick perspective on severity of injury in a consistent manner. It also allows for quick notation of pertinent negatives that may not otherwise be mentioned in times of mass casualties due to lack of time to describe each negative finding.

The Marshall Grading Scale[22,23,24,25] was considered when developing the reporting format. When data from EHR is later accessed for evidenced-based treatment and studies, this data can be consistently mined. This also simplifies where to look for the result and allows consistency in reporting with constantly changing radiologists. The ICU and neurosurgical teams can know where to look for important findings (and pertinent negatives) when dealing with penetrating casualties. Since the reports are handwritten initially and later entered into EMR, this minimizes extra writing and simplifies data entry.

The real-estate mantra holds true in TBI and especially penetrating and perforating injuries: location, location, location. Surviving ballistic injury patients are prone to neurocognitive sequelae, so each injury is closely examined for the location of the entrance, exit or resultant missile remnant, and ballistic trajectory. That third aspect, the trajectory real-estate, is possibly more important than the entrance and exit sites: one must ask, "What path did the missile take?" in an attempt to determine what neurological structures are potentially damaged.[26]

Once we become more familiar with penetrating head injury to include blast effects and available medical resources (time, blood, staff, surgical capabilities), analysis may be better estimated by determining survivable vs. non-survivable (expectant) CT findings, as well as predictability for quality of life determinations. We would like to mention that there is a telemedicine tool available for military providers for questions about TBI in general. Questions can be emailed to tbi.consult@us.army.mil by any military service. Although this is an Army email, AF and Navy (and VA) can email with questions.

The authors presented a spectrum of imaging findings in traumatic brain injury from mild to severe. This should provide a baseline of knowledge of diagnostic imaging utilization in the current conflicts and traumatic brain injury in general with evolving transformational technologies. Knowing more about how different modalities and specific sequences identify certain levels of injury can help providers order imaging more effectively.

Acknowledgements:

The authors would like to thank Dr. Seltzer, Walter Reed Medical Center, for her contribution of our third case.

Category 1 CME or CNE can be obtained on the MedPix™ digital teaching file on similar cases by opening the following link. Many Radiology Corner articles are also a MedPix™ Case of the Week where CME credits can be obtained.

http://rad.usuhs.mil/amsus.html

Head Injury Severity:	**MILD**	**MODERATE**	**SEVERE**
Structural imaging **(CT / MR)***	**Normal**	**Normal or abnormal**	**Normal or abnormal**
LOC+ Loss of Consciousness	**0-30 min**	**LOC >30 min to 24 hours**	**LOC > 24 hrs**
GCS **Glascow Coma Scale**	**13-15**	**9-12**	**< or = 8**
AOC Altered Consciousness	**A moment up to 24 hrs**	**>24 hours Severity based on other criteria**	**>24 hours Severity based on other criteria**
PTA Post Traumatic Amnesia	**0-1 day**	**>1 to 7 days**	**> 7 days**

Table 1. Clinical comparisons of mild, moderate, and severe head injuries.
*Note, structural imaging indicates CT and/ or MR, without functional acquisition.
+The "0" in Mild LOC indicates that there does not have to be LOC to meet the current definition of mTBI.
Note, this chart does not include the category of penetrating injuries; as it can bridge across these categorie.
American Congress of Rehabilitation Medicine, 1993.

Head CT:	Negative	Positive *(fill out/ circle findings)*	Skull Fx? *No Yes*	Frontal sinus fx? *No Yes Posterior*
Missile track? *No Yes*	Unilobar: ______ *lobe*	Bihemispheric	Multilobar	Transventricular
Pneumocephalus?	No	Yes		
Elevated ICP? *No Yes*	Sulci effaced *No Yes*	Basal cisterns: *Patent? Effaced?*	Midline shift: *No Yes*	*If midline shift, amount:* ______*mm*
Hemorrhage? *No Yes*	*Cisternal*	*SAH*	*IVH*	Extra-axial: *SDH EDH*
Intraparenchymal hemorrhage: *No Yes*	Volume: __*x*__*x*__*mm*	Location:	*Frontal Temporal Occipital*	*Parietal Other*: _________

Table 2. Standard report format used in a combat hospital as an example interim report during mass casualty management.

References

[1] Hoge, C.W., et al, Mild traumatic brain injury in U.S. Soldiers returning from Iraq. N Engl J Med, 2008. 358(5): p. 453-63.

[2] Defense and Veterans Brain Injury Center Working Group on the Acute Management of Mild Traumatic Brain Injury in Military Operational Settings, Clinical Practice Guideline and Recommendations; www.dvbic.org.

[3] Hammoud, D.A., B.A. Wasserman, Diffuse axonal injuries: pathophysiology and imaging. Neuroimaging Clin N Am, 2002. 12(2): p. 205-16.

[4] Lee, H., M. Wintermark, A.D Gean, J. Ghajar, G.T. Manley, P. Mukherjee, Focal lesions in acute mild traumatic brain injury and neurocognitive outcome: CT versus 3T MRI. J Neurotrauma, 2008 Aug 15. [Epub ahead of print].

[5] Bigler, E.D., C.V. Andersob, D.D. Blatter, Temporal lobe morphology in normal aging and traumatic brain injury. Am J Neuroradiol. February 2002. 23:255–266.

[6] Maguire, E.A., K. Woollett, H.J. Spiers, London taxi drivers and bus drivers: a structural MRI and neuropsychological analysis. Hippocampus. 2006;16(12):1091-101.

[7] Maguire, E.A., D.G. Gadian, I.S. Johnsrude, C.D. Good, J. Ashburner, R.S. Frackowiak, C.D. Frith, Navigation-related structural change in the hippocampi of taxi drivers. Proc Natl Acad Sci U S A. 2000 Apr 11;97(8):4398-403.

[8] Xydakis, M.S., et al, Tympanic-membrane perforation as a marker of concussive brain injury in Iraq. N Engl J Med, 2007. 357(8): p. 830-1.

[9] Xydakis, M.S., et al., Analysis of battlefield head and neck injuries in Iraq and Afghanistan. Otolaryngol Head Neck Surg, 2005. 133(4): p. 497-504.

[10] Eastridge, B.J., Things that go boom: injuries from explosives. J Trauma, 2007. 62(6 Suppl): p. S38.

[11] Okie, S., Traumatic brain injury in the war zone. N Engl J Med, 2005. 352(20): p. 2043-7.

12 Sherer, M., et al., Comparison of indices of TBI severity: Glasgow coma scale, length of coma, post-traumatic amnesia. J Neurol Neurosurg Psychiatry, 2007.

[13] Ryan, L.M., D.L. Warden, Post concussion syndrome. Int Rev Psychiatry, 2003. 15(4): p. 310-6.

[14] Tontechnik-Rechner, Sengpielaudio Online Sound Unit Conversion Program http://www.sengpielaudio.com/calculator-soundlevel.htm.

[15] Pawlaczyk-Luszczynska, M., et al., Temporary changes in hearing after exposure to shooting noise. Int J Occup Med Environ Health, 2004. 17(2): p. 285-93.

[16] Injury Update, A report to Oklahoma Injury Surveillance Participants, November 7, 1995. http://www.health.state.ok.us/program/Injury/updates/falltbi.html.

[17] Meagher, R.J., W.F. Young, Subdural hematoma, eMedicine, Nov 2, 2006. http://www.emedicine.com/NEURO/topic575.htm

[18] Ingebrigsten, T., Aspects of the management of minor head injury. Tromse University Tromso. Tromprodukt. 1998.

[19] Folio, L., S.H. Craig, B. Singleton, Answer to last month's radiology case and image: emergency decompressive craniotomy with banked skull flap in subcutaneous pocket. Mil Med, 2006. 171(6): p. vii-viii.

[20] Kermer, C., et al., Preoperative stereolithographic model planning for primary reconstruction in craniomaxillofacial trauma surgery. J Craniomaxillofac Surg, 1998. 26(3): p. 136-9.

[21] Karolyi, D.R., M.E. Mullins, Creation and utilization of standardized reporting forms for resident preliminary reports. Scientific Poster at Association of University Radiologists, March 2008.

[22] Marshall, L.F., H.M. Eisenberg, J.A. Jane, et al., A new classification of head injury based on computerized tomography. J. Neurosurg, 1991. 75, s14–s20.

[23] Marshall, L.F., et al., The diagnosis of head injury requires a classification based on computed axial tomography. J Neurotrauma, 1992. 9 Suppl 1: p. S287-92.

[24] Guidelines for the management of severe head injury. Brain Trauma Foundation, American Association of Neurological Surgeons, Joint Section on Neurotrauma and Critical Care. *J Neurotrauma*. 1996; 13:641–734.

[25] Vos, P.E., et al., Evaluation of the traumatic coma data bank computed tomography classification for severe head injury. J Neurotrauma, 2001. 18(7): p. 649-55.

[26] Willson, T., L. Folio, Severe epistaxis from an intracranial vascular bleed from grenade injury. Military Medicine. 2008 Sept;173(9): xvii, xviii.